A White Paper on Future Federal Communications Commission Spectrum Policy

Submitted by Motorola

August 30, 2002

Table of Contents

Executive Summary 1

1 Cooperative Ad-Hoc Wireless Networks 4

1.1 Introduction 4

1.2 Summary of the Shepard Dissertation [3] 4

1.3 Summary of the Gupta/Kumar Paper [4] 7

1.4 Cell Splitting to Increase Cellular System Capacity 10

1.5 Recommendations for Research on Cooperative Networks 11

1.6 Recommendations for FCC Policy Evolution to Accommodate Cooperative Ad-Hoc Networks 11

2 Spectrum Management Policy 14

2.1 Introduction 14

2.2 Anticipated User Requirements 14

2.3 Why is Licensed Spectrum Below 3.7 GHz Required for Future Commercial Mobile Radio Systems? 15

2.4 Spectrum Above 10 GHz is Well Suited for Unlicensed Services 17

2.5 Spectrum Planning 18

3 Future Unlicensed Spectrum 20

3.1 Unlicensed Rules 20

3.1.1 Scope of rules 20

3.1.2 Reasons for New Rules 21

3.1.3 Proposed New Rules 21

3.2 Spectrum Sharing / Underlay of Unlicensed Transmitters 22

4 Experimental Licensing and Spectrum 25

4.1 Set-aside Spectrum for Pro-active System Development 25

4.2 Access to Government Spectrum for Export Development 25

4.3 The Current FCC Experimental Licensing Plan is Efficient when non-Government Spectrum is Requested. 26

References 27

Appendix A - Definitions 28

Appendix B - Smart Radio vs. Cognitive Radio 29

Appendix C - The Potential Effects of Underlay Systems on Licensed Services: Two Examples 31

Executive Summary

This white paper has been prepared by Motorola to provide the Federal Communications Commission Spectrum Policy Task Force with information on the subjects of 1) cooperative ad-hoc wireless relay networks, 2) future-generation communication system requirements for wide-area mobile systems, 3) recommendations for changes in spectrum policy for both licensed and unlicensed spectrum, and 4) the allocations of spectrum for experimentation.

- Recent presentations to the FCC Technological Advisory Committee by Dr. David Reed and archival research works by Dr. Timothy Shepard and Profs. Gupta & Kumar have been reviewed and commented upon. These works propose that cooperative ad-hoc wireless relay networks can support any foreseeable user communication requirements. With certain assumptions, these cooperative relay networks achieve a system capacity that grows in proportion to $\sqrt{N}$ where N is the number of users. At the same time, the per-user capacity decreases in proportion to $1/\sqrt{N}$. This promise of unbounded system capacity has motivated further research to validate the results using less stringent assumptions and to solve a number of problems identified in the original research. Specifically, Motorola believes that the practically achievable capacity of these cooperative networks is not yet known and the following issues must be addressed to evaluate application of this potentially revolutionary technology:
  - The simulation work reported on by Shepard must be extended to include other propagation models and to include shadow loss.
  - A means must be developed to mitigate the severe congestion problem identified by Shepard in his analysis.
  - The latency experienced by users requiring multi-hop connections must be evaluated and, if unacceptable, reduced.
  - System performance analysis with user mobility must be evaluated and a means developed to update routing tables very rapidly.
  - Hybrid applications that efficiently combine cooperative relay with conventional cellular technology must be developed. Motorola suggests that hybrid applications of cooperative relay may yield positive results.

  Motorola recommends that the Commission proceed with caution regarding rules changes to accommodate cooperative ad hoc wireless networks until the results of further research are available. Further, it is not clear that cooperative ad hoc wireless relay systems must be implemented in unlicensed spectrum; Motorola suggests that these systems may, in fact, achieve their best performance within licensed spectrum where all users are able to cooperate.

- Motorola has developed a vision for future generation mobile communications systems. This vision proposes mobile users using very high data rates (tens of Mbps on the base-to-mobile link) over a wide area with high reliability and low latency. A goal of these systems is to provide the mobile user with communications capability very similar to what he/she experiences in the office or home. This vision does not, however, preclude next generation systems having other features with possibly lower information rates. Motorola believes that

- o The economic viability of future mobile systems requires that wide-area (cell radius much larger than current WLAN) coverage must be deployed using current 2G cellular sites at system start up.
- o Because required transmit power is proportional to information rate and because path loss increases with increasing carrier frequency, the technical success of these systems requires that the carrier frequency be below 6 GHz and preferably below 3.7 GHz.
- o The required efficiency of these systems can only be achieved in a licensed band where interference may be controlled.

- ▪ Motorola supports the pending WECA petition for additional unlicensed spectrum at 5.470-5.725 GHz. Motorola also believes that frequencies above 10 GHz are well suited for future allocations of unlicensed spectrum beyond the currently pending petition, due to reduction of interference between systems and the availability of large bandwidths. Given that future wide-area mobile systems require spectrum below 6 GHz, such systems should be given preference to those frequencies over other systems such as unlicensed, that do not absolutely require frequencies below 6 GHz. The Commission is urged to accommodate the requirements of future wide-area mobile systems in the planning of future spectrum allocations in the 1 to 6 GHz bands. Within 1-6 GHz, the cost of coverage would increase as the frequency of operation approaches 6 GHz.

  Motorola recommends a framework for coexistence in future unlicensed spectrum to provide for equitable access to and utilization of the spectrum without disadvantage to particular uses in congested environments. New rules are proposed to improve reuse efficiency, control interference, provide for high quality of service, and enable harmonious coexistence of many different uses and devices in the spectrum. The rules include channel definitions, power control requirements, spectrum access rules, and limits on spectrum use that provide a framework for the development and evolution of industry standards. These rules should apply to future unlicensed spectrum allocations and be developed in advance of such allocations.

  Underlaying unlicensed transmitters on spectrum that is authorized for licensed services is problematic. This concern applies to all licensed services, but is particularly acute with critical operations such as public safety. Motorola believes that several factors reduce the ability of a smart and/or cognitive radio to protect the primary users of the spectrum. These factors are difficult to control and predict and are a subject of on-going Motorola research. They include

  - o Shadowing of the smart and/or cognitive radio antenna with respect to the licensed transmitter, resulting in unintended interference.
  - o Inability of the smart and/or cognitive radio to look ahead in time, resulting in interference to future licensed transmissions.

    - Power transmitted by the smart and/or cognitive radio creating an exclusion zone; i.e., a zone wherein (a) interference to licensed receivers results and (b) the area and shape of the zone is a function of the propagation path loss between licensed receivers and the smart and/or cognitive radio.

- Finally, on the topic of experimental licensing and spectrum, Motorola notes that the current FCC experimental licensing plan is quite efficient in most respects. However, we do recommend that the Commission take additional steps to support pro-active system development. In some cases, it may be appropriate to even designate a band segment for development, which would allow U.S. companies to be more competitive in the global market. For example, the Commission should consider designating a relatively small block of spectrum (e.g., 50 MHz) between 2 and 4 GHz for advance development of wide-area mobile systems. The choice of this spectrum should also be part of a long-term plan for spectrum allocation to support future wide-area operations. In addition, we propose improvements in cycle time for granting access to Government spectrum for testing of equipment destined for export, including providing the Commission with the ability to analyze the impact of interference to Government spectrum.

1 Cooperative Ad-Hoc Wireless Networks

1.1 Introduction

A recent presentation [1] to the FCC Technological Advisory Council (TAC) and submission to the Commission in response to ET Docket No. 02-135 [2] have proposed the application of cooperative relaying from user to user as a means of increasing the capacity of wireless communications networks. The foundations for this proposal are the 1995 Ph.D. dissertation of Timothy Shepard [3] and the recent journal paper by P. Gupta and P. Kumar [4] both of which demonstrate that the total capacity of a network exploiting cooperative relaying grows as the number of users grows. Dr. Reed has, in [1] and [2], suggested that cooperative relaying should be carefully considered for future wireless networks and that the Commission should take the possibility of cooperative relaying into account in modifications to spectrum policy. In Dr. Reed's work, cooperative relaying is not applied in isolation but along with other advanced communication techniques such as multiple-input multiple-output systems, fast dynamic spectrum management [5], multi-user detection, and multipath exploitation techniques. Motorola supports the consideration of these revolutionary concepts by the Commission but notes that a great deal of research will be required to successfully apply these concepts. Motorola therefore recommends that the Commission proceed with caution in the modification of rules to accommodate these technologies. Ongoing research efforts within Motorola are addressing some of these revolutionary concepts.

The purpose of this section is to identify research topics that must be addressed before efficient cooperative relaying can be widely utilized. The works of Gupta/Kumar and Shepard will be very briefly summarized and then related to the well-known technique of cell splitting [6]. The section concludes with recommendations regarding the possible cautious evolution from current spectrum policy to a policy supporting these communications concepts. The concept of cooperative relaying is not new; technology for packet relay networks was developed more than 15 years ago for the U.S. Department of Defense [7] and was an active topic in the creation of the standards for Third Generation Systems where it was part of a broader concept called Opportunity Driven Multiple Access (ODMA) [8]. In addition, "ad-hoc networking" is the topic of much research in universities throughout the world; often, however, the focus of this research is on routing strategies rather than on capacity enhancements for the physical layer of a system.

1.2 Summary of the Shepard Dissertation [3]

Shepherd's 1995 Ph.D. dissertation at Massachusetts Institute of Technology presents an initial system design and analysis for a cooperative ad-hoc network of user stations that communicate between one another without the aid of any fixed infrastructure. A key conclusion of this work is that, under certain assumptions, reliable communication *between nearest neighbors* is possible for an arbitrarily high user spatial density. That is, the number of users within a fixed circular service area may grow without bound! Dr. Shepard first analyzes the signal-to-interference ratio (SIR) that a user communicating with a nearest neighbor would experience showing that SIR decreases slowly with number of randomly placed users in a circular service area with fixed radius. Dr. Shepard shows that signal-to-interference ratios in the range of –10 to –20 dB will be experienced as the number of users becomes very large and proposes to use spread spectrum technology [10] to enable communications at these low SNRs; the processing gain of the spread-spectrum radio is selected such that the E_b / N_0 for communications is sufficient. It is important to note that this analysis is considering the communication link between any user and its nearest neighbors. As part of the interference analysis, the system design proposes a strategy for mitigating the possibly strong interference from nearest neighbors. Interference mitigation is accomplished by having each user create a transmit/receive schedule and communicating this schedule with nearest neighbors. A user transmits to a neighbor only when the schedules of the user and its neighbor allow transmission by the user and reception by the neighbor.

Shepard has made the following key assumptions in his analysis:

- A free-space model is used for path loss; that is, received power is proportional to $1/r^2$ where r is the distance from transmitter to receiver. Motorola notes that in most cellular system analyses received power is assumed proportional to approximately $1/r^4$ but that the higher path loss exponent (4 versus 2) will improve the performance of the system proposed by Shepard. Also, for very short range the free-space model is indeed applicable.
- Multipath fading has been ignored in the analysis. Motorola notes that frequency selective fading is usually included in cellular systems analyses but that, in the limit, when user density is very high and therefore users are very closely spaced, direct line-of-sight communications is experienced and frequency selective fading may be less of an issue.
- Shadow loss [9] has been ignored in the analysis. Motorola believes that shadow loss must be included in a system analysis before firm conclusions regarding the system efficiency may be deduced.
- Successful communication is assumed to be possible when signal-to-interference ratio is larger than the limit established by the well-known Shannon capacity formula:

  $$SIR \geq \alpha \left(2^{C/W} - 1\right)$$

  where C is the transmission rate, W is the bandwidth, and α is a factor used to incorporate a margin into the analysis. Note that this formula is applicable only to communications over a static (non time varying) channel with additive white Gaussian noise interference. Motorola believes that this is a reasonable model for a first analysis.
- The user density is assumed to be large enough that the system is interference limited and thermal noise has been ignored.
- Latency has been ignored.

As stated previously, the first result of the dissertation is the calculation of signal-to-interference ratio for communication between a user and its nearest neighbor. M users are randomly placed within a circle with radius R resulting in a user density of $\rho = M/(\pi R^2)$ and an average distance between a user and its nearest neighbor $R_0 = 1/\sqrt{\rho}$. Ignoring interference from the nearest neighbor itself, the signal-to-interference ratio is shown to be

$$SIR = \frac{1}{\eta \, \pi \ln\left(M/\pi\right)}$$

where η is defined to be the duty-factor for the user. Interestingly, SIR is not a function of the user density ρ. Shepard presents a graph (Figure 2.1 of [3]) illustrating SIR as a function of M with η as a parameter. These graphs show SIR approaching –20 dB for a very large number of users assuming $\eta = 1$. Motorola has extended these results to show the per user bit rate as a function of M assuming 1) the use of a good turbo code[1] that can achieve a bit error rate of 10^{-4} at $E_b/N_0 = 1$ dB; 2) an available bandwidth of 5 MHz; and 3) a continuously variable spread-spectrum processing gain that is adjusted to provide exactly the E_b/N_0 needed by the turbo code. Figure 1 illustrates these results. These results show that per user information rate for a system using a 5 MHz band, while decreasing, remains at least 12 kbps for very high user densities. This rate is well below the rates being currently considered for third generation cellular systems.

The analysis of the communications between a user and its nearest neighbor is useful in that it has suggested that the capacity of a cooperative wireless network may be unlimited under certain conditions. As recognized and studied by Dr. Shepard, the nearest-neighbor communication problem is the starting point for more detailed analysis that includes communications between all users in the system. Shepard considered a system having 1000 users randomly placed in a 10 km square. Considering the possibility that any user may wish to communicate with any other user, there are one million potential relayed communication paths in this system. Shepard considers several different routing algorithms and determines that an algorithm that selects the least-cost path in terms of total transmitted energy is the better of the algorithms considered. Using this routing algorithm, Shepard then shows that a significant number of stations are a node in more than 100,000 (out of one million) paths. That is, a significant number of users must relay the data for 10% of the total number of users. Thus, Dr. Shepard has identified a very serious congestion problem associated with the unlimited growth of a cooperative relay network. This result is based on the assumption that the destination for each user's traffic is uniformly randomly selected from all system users. The congestion problem is less difficult as the traffic pattern becomes more localized (i.e. users are more likely to communicate to nearby destinations) and the problem vanishes when only nearest-neighbor communications is considered.

[1] The code used is a rate- 1/3 serially concatenated turbo code using 6 iterations of turbo decoding. It is composed of a 4-state rate ½ recursive convolutional code and a 4-state rate 2/3 recursive convolutional code. The interleaver length of the turbo code is 1024.

The use of access points and tunneling was suggested by Shepard as a means of mitigating the congestion problem. At the access point a message could be placed on a wired (perhaps fiber) connection for transport to another location in the system where the message would again be placed on the relay network for delivery to its destination. Using these wired tunnels the system becomes a hybrid system taking advantage of relays only where advantageous. Motorola notes that relaying to enhance a conventional cellular system has been considered by the industry. Detailed research results on this topic are not available to us, however, it has been noted that if all cellular traffic was relayed through the network to the mobile units closest to the cell site (access point), the mobile units closest to the cell sites would be required to collectively process the load from the entire cell. An advantage of this concept is that the cell site maximum transmit power could be greatly reduced perhaps allowing more dense frequency reuse thus increasing spectrum efficiency. This is another instance of the congestion problem identified by Dr. Shepard.

Another important issue affecting cooperative ad-hoc networks is the maintenance of routing tables in a system where connectivity is constantly changing due to user mobility. Routing table maintenance in a dynamic environment is the subject of much ongoing research. Motorola suggests that current research results be reviewed and that a detailed system simulation be created to evaluate performance (including the performance of routing table maintenance) of the system proposed by Dr. Shepard in a realistic environment.

In summary, Shepherd's analysis is the first to show that the total system capacity of a cooperative ad-hoc wireless network actually increases with increasing user density. Unfortunately, a serious congestion problem is identified that could limit the application of the proposed system. The promise of Shepherd's system is important and his results should be extended and verified by simulation or, where possible, analysis. Rule changes by the Commission to accommodate this system should be delayed pending the evaluation of an extended study.

1.3 Summary of the Gupta/Kumar Paper [4]

Gupta and Kumar at the University of Illinois also considered a wireless network that consists of n nodes that communicate with one another. A data packet generated at a source node is routed to its destination node through a series of hops over intermediate nodes as in the Shepard work. There is no central access point nor is there a central controller. Two metrics are defined to measure the ability of the network to relay information. First, the network is said to transport one bit-meter when one bit of information has been successfully transported a distance of one meter towards its destination. The *transport capacity* of the network is the total number of bit-meters that the network can transport in one second for all n nodes. Second, the network is said to have a *feasible throughput* of $\lambda(n)$ bits/sec, if it is possible for every node to transmit at an average data rate of $\lambda(n)$ bits/sec to its chosen destination. Given this framework, the authors show that, (a) a wireless network can achieve a transport capacity that increases (details below) with the number of nodes in the network, and (b) the maximum feasible throughput of a network decreases (details below) as the number of nodes in the network increases.

The assumptions and definitions for this work are:

- The n nodes are distributed randomly on a disk of unit area with a uniform probability density.
- Propagation: As in the Shepard analysis, a free-space model for path loss is used, multipath fading is ignored, and shadow loss is ignored. Motorola's comments regarding these issues are the same as above.
- The maximum transmission rate for any node is denoted W. M sub channels with rates W_m bits/second, where $1 \le m \le M$ and $W = \sum_{m=1}^{M} W_m$, are defined. Each node can utilize any subset of these sub channels.
- For any transmission, a destination node is randomly selected. The resulting average distance between a source and its destination is denoted L.
- Time slots of length τ seconds are defined. All nodes are slot synchronized.
- By definition, the network transports $\lambda(n) \times n \times T$ bits during T seconds.
- Transmissions are successful if a signal-to-interference ratio constraint is met. Specifically, given that a subset of nodes in the network are transmitting simultaneously over a specific sub-channel, each individual node in the subset is able to transmit successfully to its destination if the signal-to-interference ratio experienced for the transmission is greater than β. That is, if S_m is the set of nodes using sub-channel m, then for node $l \in S_m$ at location X_l to transmit successfully to node j located at X_j the following must hold

$$\frac{\dfrac{P_i}{\left|X_i - X_j\right|^{\alpha}}}{N + \sum\limits_{\substack{k \in S_m \\ k \neq i}} \dfrac{P_k}{\left|X_k - X_j\right|^{\alpha}}} \ge \beta$$

  where P_i is the transmit power of node i, N is the background noise level, and α is the propagation path loss exponent.
- A central controller is assumed to know the locations and traffic requirements for all users in the system. The controller determines the routes for all messages as well as the transmit power and scheduling for all transmissions.
- Users are in fixed locations enabling the central controller to create the routing tables uses for all communications.

Using these assumptions and definitions, it is shown that

- The transport capacity of the network is bounded above by

$$\lambda(n) \times n \times L \le \left(\frac{2\beta + 2}{\beta}\right)^{\frac{1}{\alpha}} \frac{1}{\sqrt{\alpha}} W\, n^{\frac{\alpha - 1}{\alpha}}$$

For a path loss exponent of $\alpha = 2$ the transport capacity increases in proportion to $\sqrt{n}$; this is the result quoted by Reed in his presentation to the FCC Technological Advisory Committee. Observe that this is an upper bound and not necessarily an achievable limit.

- There exists a placement of nodes and an assignment of traffic patterns such that the network can achieve a transport capacity of

$$\frac{1}{\left(16\beta\left(2^{\frac{\alpha}{2}} + \frac{6^{\alpha-2}}{\alpha-2}\right)\right)^{\frac{1}{\alpha}}} \frac{Wn}{\sqrt{n}+\sqrt{8\pi}} \text{ bit - meters/sec}$$

  This result shows that, for large n, the *achievable* transport capacity again increases in proportion to $\sqrt{n}$ but at the expense of the assumption that nodes are placed carefully. Since node placement is random in a real system, this result must be used with extreme caution.

- For the case where each node transmits at a data rate of $\lambda(n)$ bits/sec to a destination chosen randomly, it is shown that "with high probability", a throughput of

$$\lambda(n) = \frac{cW}{\sqrt{n \log n}} \text{ bits/sec}$$

  is feasible but a throughput of

$$\lambda(n) = \frac{c'W}{\sqrt{n}} \text{ bits/sec}$$

  is not feasible, for some constants c and c'. In other words, the *data rate at which each node in the network can transmit to its desired destination* ***<u>decreases</u>*** *as the number of nodes in the network increases*.

These results are consistent with the results derived by Shepard using a more simplified analysis. Gupta and Kumar, however, do not address the congestion problem identified by Shepard. Motorola notes that these results do not take latency into account. Further analysis or simulation to estimate system and user throughput when a latency constraint is included is recommended.

In summary, Gupta and Kumar have provided an extension of the work of Shepard by analyzing the capacity of a cooperative wireless ad-hoc network. It is shown that the total system capacity grows faster than the number of users but that the per user capacity decreases as the number of users increases. The issues of congestion and of distributed routing mechanisms remain to be addressed. As stated previously, routing mechanisms are the subject of much ongoing research that has not yet been considered in this overview. In the extension of these results, latency should be explicitly considered. As was the case for Shepherd's work, the promise of this work is important and could have great impact on the issue of spectrum availability. However, Commission rule changes to accommodate this work should await the results of further research.

1.4 Cell Splitting to Increase Cellular System Capacity

Both of the results discussed above show that the spectrum efficiency in terms of information bits per second per Hertz of bandwidth per unit area increases without bound as the number of users per unit area increases also without bound. A similar result is well known for classical ideal cellular systems. In [6], McDonald presents the concept of *cell splitting* for cellular systems. Consider an ideal cellular system composed of hexagonal cells using omni directional antennas at each cell site. The spectral efficiency, η, of this system is defined as the total number of information bits per second per Hertz of bandwidth per cell site that the system can support. An alternate definition of spectral efficiency accounts for the area of a hexagon yielding the total number of information bits per second per Hertz of bandwidth per unit area. Denote this alternate definition of spectrum efficiency by η'.

Suppose that the total bandwidth available to this system, W, is split into M sub-channels. The frequency reuse factor for such a cellular system is defined as the number of contiguous cells that share the available set of channels. Hence, if the reuse factor is *N*, the number of channels available per cell is *M/N*. A reuse factor $N=7$ is illustrated in Figure 2; the integer within each hexagon indicates the channel subset used in that cell. A very simplified analysis[2] of the system [9] shows that the worst-case base-to-mobile signal-to-interference ratio for a mobile at the boundary of the cell in an ideal hexagonal system satisfies,

$$\mathrm{SIR}_{\min} \geq 10n\log_{10}\left(\sqrt{3N}-1\right)-7.78\ \mathrm{dB}$$

where n is the path loss exponent and N is the frequency-reuse factor. Notice that the radius of the hexagonal cells can be altered without affecting $\mathrm{SIR}_{\min}$ as long as the reuse factor *N* is held constant. Therefore, splitting the cells as shown in Figure 2 does not affect the spectral efficiency η. However, since the physical area occupied by each cell is now reduced, the spectral efficiency η' is higher.

It is correctly concluded from this analysis that the spectral efficiency, η', achievable by a ideal classical cellular system can grow without limit using cell splitting. However, several issues limit this unbounded increase in spectrum efficiency. First, repeated cell splitting will eventually bring the base stations so close together that the path loss exponent will decrease causing a loss in capacity. Second, the cost of installing and maintaining a large number of base stations may not be economical. Ignoring the cost, obtaining real estate for cell sites is a difficult problem for cellular service providers. Motorola notes that the use of mobile units as pseudo cell sites as described by Dr. Shepard appears to solve the real estate problem of the classical cell splitting concept.

Under the ideal conditions stated above, both the cooperative ad-hoc wireless network and the conventional cellular network can achieve unbounded spectrum efficiency thereby conceptually servicing any future user spectrum needs in a finite bandwidth. A

[2] The analysis in [9] is highly simplified. The result is an underbound because distances to interferers have all been presumed equal to distance to the nearest interferer. The result shown here should not be used for detailed system design.

fundamental difference between these systems is that the ad-hoc network has no connection to the fixed wireline network and the conventional cellular network connects to the wireline network once within each cell. It was suggested in [3] that the congestion problem might be mitigated by including access points in the system enabling messages to be tunneled to other locations in the network possibly via a wireline connection rather than being relayed across the network. This suggests that a hybrid network using relaying and cell sites (access points) might be a practical means of improving spectrum efficiency thereby limiting the need for large additional spectrum allocations.

1.5 Recommendations for Research on Cooperative Networks

Motorola believes that the application of cooperative ad-hoc wireless networks would be expedited by addressing the following research issues:

- Extend Dr. Shepard's results [3] through an exhaustive system simulation effort that takes other path loss models, fast fading, mobility, and shadow loss into account.
- Develop concepts for a hybrid cellular and ad-hoc cooperative network that wisely uses access points in a cooperative ad-hoc wireless network to mitigate the congestion problem and increase the per user information transfer rate. Evaluate the capacity of these systems analytically or via system simulation. This research should include the detailed evaluation of a possibly new physical layer as well as higher layer processing to support high-speed relay.
- Develop concepts for integrating the use of high performance radio resource management techniques such as those being considered for the DARPA XG program [5] with the concept of cooperative ad-hoc wireless networks.

1.6 Recommendations for FCC Policy Evolution to Accommodate Cooperative Ad-Hoc Networks

The theoretical promise of cooperative wireless networks is the unlimited increase in system capacity *using a finite bandwidth*. If indeed this result is achieved, there would be no shortage of spectrum and it would not be necessary to allocate vast amounts of spectrum for this use. Of course, practical issues will limit the capacity of these networks. The practically-achievable capacity of cooperative wireless networks is not known at this time. *Motorola believes that it is premature for the Commission to proceed forward with regulatory policy based on the early state of research in cooperative relaying. Further, it is not clear that cooperative ad-hoc wireless networks are best served in unlicensed spectrum. Motorola believes that a cooperative ad-hoc wireless network will be more likely to meet its promise if it is carefully engineered and not degraded by currently unpredictable interferers*. Smart relaying requires that all users, not disjoint subsets of users, be able to cooperate by relaying one another's messages. It is not clear that a mix of technologies in unlicensed spectrum could collectively support a cooperative ad-hoc network. To some extent, cooperative networks can be accommodated in spectrum currently available for unlicensed use or even in some licensed bands. Accordingly, Motorola recommends that, if any additional accommodation is made for cooperative systems at this time, only a small amount of spectrum be identified for experimentation with these concepts. If the promises are met in the experimental systems, additional spectrum could be allocated. Motorola believes that the details of the technology for these systems will require years to develop.

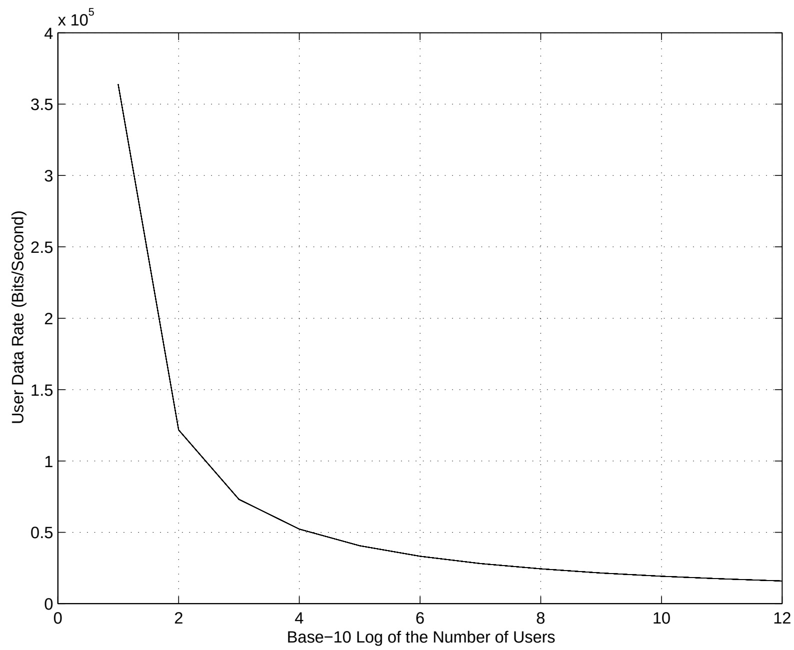

Figure 1. Per-user information transfer rate as a function of the number of users for the system proposed in [3]

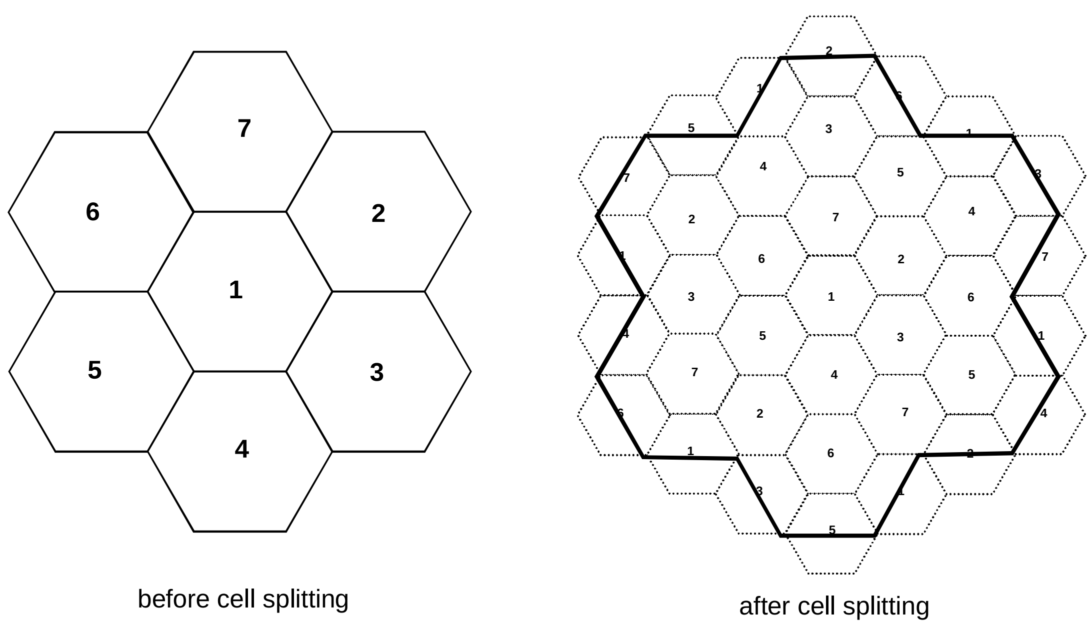

Figure 2. Seven-cell frequency reuse and cell splitting.

2 Spectrum Management Policy

2.1 Introduction

Although there is considerable uncertainty in the telecommunications marketplace at this time, Motorola remains confident that there will continue to be an increasing demand for very high speed, reliable, nearly ubiquitous wireless communications by mobile and nomadic users and that additional spectrum will be required to meet this demand. Further, Motorola believes that this need will be served most efficiently by an engineered system operating in a licensed band of frequencies below 3.7 GHz. The system may or may not make use of cooperative relaying depending on the timeliness of the research suggested in Section 1 of this white paper. The following sections present high-level requirements for this wireless system as well as arguments for why the system should be implemented below 3.7 GHz in licensed spectrum.

2.2 Anticipated User Requirements

It is anticipated that users will wish to exchange data at rates of several tens of Megabits per second (Mbps) both while moving a vehicular speeds (up to 120 km/h) and while stationary or moving slowly (nomadic). Systems having lower information transfer rates are not precluded from this vision, however, high-data-rate systems are particularly challenging with regard to wide-area coverage. Users will want nearly ubiquitous[3] service that is highly reliable (perhaps better than 95% coverage reliability along with message error rates usable for video streaming and file transfer) where service availability is claimed and which provides the low latency needed for two-way streaming and Internet browsing. That is, it is expected that users want the ability to recreate the broadband wireline experience of being in the office (100BaseT) or at home (DSL or cable modems), even when they are traveling. The commercial success of this system will depend on its cost to the user; cost per transmitted information bit must be very very low for wide public acceptance. This vision of very-high-speed very-low-cost wireless data implies a fundamental shift in the way people communicate similar to the shift that occurred with the advent of the portable cellular telephone during the 1980s. Current, wide-area cellular communications systems are largely low bit rate and voice-centric. Third generation system may be able to provide 384 kbps (2 Mbps in some locations) in the near future however the latency of 3G systems is not expected to compare favorably with broadband wireline.

The current public literature includes descriptions of systems that partly meet these requirements using a combination of current Third Generation (3G) cellular technology, e.g. WCDMA, working cooperatively with Wireless Local Area Network (WLAN) technology. WLAN technology is able to provide information rates and latency comparable to current cable systems. The WLAN technology is used to provide coverage in hot-spots such as airports, hotels, and coffee shops. Motorola notes that WLAN technology has, by design, a small coverage area making ubiquitous coverage economically unfeasible. Furthermore, WLANs are not designed for the co-channel interference environment of cellular applications thus making cellular deployment spectrally inefficient. Motorola believes that, while these "Beyond 3G" systems will certainly be implemented, they do not support the vision described above. No other current wireless technology supports the vision described above so that the supporting technologies must be developed. The Commission can support this development through the identification and allocation of appropriate spectrum.

2.3 Why is Licensed Spectrum Below 3.7 GHz Required for Future Commercial Mobile Radio Systems?

In order for the vision of future mobile radio systems to be economically viable at start-up, Motorola believes that the base sites for the system must be co-located with current cellular base sites. The cell radius for urban/suburban deployment of current cellular systems is several kilometers[4] and this radius defines the cell radius for the start-up future generation wide-area very-high-data-rate system. The following table summarizes some of the requirements of a future generation system and compares them to the Motorola view of similar requirements for unlicensed systems.

Unlicensed	Licensed Wide-area mobile
Short range (up to 100m)	Long range, on order of multiple kilometers
Up to pedestrian speeds	Up to vehicular speeds
Low delay spreads (ns range)	Larger delay spreads (μs range)
Mostly LOS propagation	Mostly NLOS propagation

It is clear from the table that unlicensed systems, while they may complement licensed systems, are short-range systems and thus would not be suitable for implementing the future generation vision. Furthermore, the range difference between future generation systems and unlicensed systems implies that the spectrum assignments should be different, favoring lower frequencies for the wide-area systems high data rate systems and higher frequencies for the short range unlicensed systems. The question of where the spectral ceiling is in regards to wide-area mobile systems is a question that frequently arises as higher data rate services are contemplated. A partial answer to this question can be found by considering the system, device and propagation physics and facts presented below.

1. **<u>The required transmit power is directly proportional to the data rate [9]</u>**. Thus, each doubling of information rate doubles the required transmitter power all

[4] The region serviced by a single cell site varies widely making the specification of a single range impossible. However, a general statement can be made that service range is on the order of multiple kilometers rather than on the order of hundreds of meters.

other factors (modulation scheme, error correction coding, range, multipath, etc) being the same.

2. **Infrastructure cost is inversely proportional to the cell size**. One of the largest costs in deploying a cellular system is the cost of real estate for cell sites and the base station radio equipment itself. Therefore, maximizing cell radius at system start-up is essential to economic viability. For example, if the cell radius is reduced by a factor of 2, the number of cells and thus the cost required to cover a geographic area would increase by a factor of 4.

3. **Path loss is frequency dependent.** Assume that a free-space path loss model [9] is applicable between the transmitter and some distance d_0 and that path loss is proportional to $(d_0/d)^3$ for distances larger than d_0. The free-space component of this model yields a received signal strength at an isotropic receive antenna that is inversely proportional to f^2. Thus, received signal power will decrease by a factor of 100 when carrier frequency is increased from 1 GHz to 10 GHz. The decrease in coverage range associated with this increase in carrier frequency is, assuming that the $(d_0/d)^3$ proportionality does not change with frequency, $\sqrt[3]{100} = 4.64$ and the area covered by a cell site is reduced by a factor $4.64^2 = 21.5$. Therefore an increase in carrier frequency of a factor of 10 will increase the number of cells required to cover a specified area by a factor of more than 20. In theory, the loss in signal range can be recovered with high gain antennas. However, in a mobile system, the high gain antenna would need to be adaptive and would need an impractically large number of antenna elements[5]. For example, increasing the carrier frequency from 1 to 10 GHz while increasing the data rate by a factor of 10 would cut 30 dB from the link budget, which would require a 1000 element array to compensate.

4. **Propagation becomes line-of-sight at very high frequencies**. As frequency increases, signals lose the ability to penetrate and travel around objects. If a clear line-of-sight path does not exist between the transmitter and the receiver, the signal is effectively blocked. This effect becomes more dramatic as the frequency increases and the effect is expected to become significant above 6 GHz. In a mobile system, the subscriber antenna is close to the ground and it is difficult to ensure line-of-sight to the serving base station.

5. **Doppler frequency shift is proportional to the product of the carrier frequency and terminal speed.** That is, $f_d \propto F_c v$, where f_d is the maximum Doppler shift, F_c is the carrier frequency and v is the mobile speed. The rate of variation of the time-varying fading channel being experienced on a mobile radio link is directly proportional to f_d. The time-varying channel must be estimated and tracked in the receiver for the purpose of coherent detection. Advanced techniques such as interference cancellation and adaptive antenna processing also require accurate channel estimates. Known pilot symbols and/or training

[5] Adaptive directional antenna technology is the subject of ongoing research at Motorola and many other equipment manufacturers and universities.

sequences are periodically inserted into the transmitted data stream to support channel estimation and tracking in the receiver. In order to satisfy the Nyquist criteria, the pilot symbols or training sequences must be transmitted at least $2f_d$ times per second. As F_c increases, the required overhead for channel estimation increases proportionally.

Consider a future wide-area mobile system using a 20 MHz bandwidth and a carrier frequency of 3.7 GHz. Using only the issues above it can be argued[6] that an unacceptably large amount of transmit power are required to support the radio link. While large amounts of power may be available at the base station, large transmit powers are not possible in most subscriber units. Thus, designing a system meeting the future mobile communications wideband vision is extremely difficult even at 3.7 GHz and it is essential that carrier frequency not be increased significantly beyond this limit. Higher carrier frequencies may unacceptably limit the achievable uplink information transfer rates or the coverage range or both. In reality, the solution for the broadband mobile system design would be a combination of: reduced cell size, high base station EIRP, asymmetry in the RF link (i.e., the uplink would have a smaller bandwidth), and advanced system and modulation & coding techniques (e.g., small adaptive array at subscriber unit and a reasonable array at the base).

Through careful system design and the application of advanced signal processing techniques, Motorola believes it is possible to utilize carrier frequencies up to approximately 6 GHz for broadband mobile services. Even though carrier frequencies up to 6 GHz may be possible, frequencies below 3.7 GHz are preferred. Others have also indicated [12] that 6 GHz is an upper bound. The 6-10 GHz range is a gray area where it is doubtful that broadband mobile services could be economically feasible.

2.4 Spectrum Above 10 GHz is Well Suited for Unlicensed Services

Motorola supports the pending WECA petition for additional unlicensed spectrum at 5.470-5.725 GHz. Motorola also recommends that new spectrum for unlicensed service beyond that considered in the current petition be located in bands above 10 GHz. Due to path loss characteristics and other sources of signal attenuation, the bands above 10 GHz are better suited to high-density (i.e. dense frequency reuse) small-scale networks. Additionally, the total available bandwidth above 10 GHz is much greater than the bandwidths below 10 GHz thus enabling large future allocations of unlicensed spectrum, if needed, while not negatively impacting the ability of the Commission to make spectrum available for wide-area mobile systems that require spectrum below 10 GHz.

This position is supported in NTIA Report #94-306 [13] that considered the use of 900 MHz, 11.4 GHz, and 28 GHz as possible bands for Personal Communications Services (PCS). The report has some unique findings that suggest the bands above 10 GHz are ideal for low power, short distance communications such as unlicensed PC networking. The report states that residential dwellings have high room-to-room attenuation due to the absorption rate of typical construction materials. Any aperture

[6] Apply the relationships of items 1 and 3 above starting from the currently used transmit power of 150 mW for IS-136 at a carrier frequency of about 800 MHz.

such as a window or doorway will conduct signals above 10 GHz like a waveguide above cutoff. Therefore, a pole-mounted antenna outside of a dwelling can be used to communicate into the home provided the antenna is placed near the window. The attenuation of the walls will reduce room-to-room (apartment-to-apartment) interference. This leads to efficient frequency reuse without complicated and expensive systems to manage the interference. The NTIA report also found that signals propagated better at the higher frequencies in buildings with metal walls such as office and industrial buildings. This is an advantage for business that might wish to build wireless networks within sections of their building.

Therefore, Motorola recommends that future unlicensed spectrum allocations beyond the current WECA petition be allocated above 10 GHz. These frequencies provide a reduction of interference between systems and the availability of large bandwidths. Given that future wide-area mobile wireless systems require spectrum below 6 GHz to be economically viable, Motorola believes that these systems should be given preference to these frequencies over other services that do not absolutely require this spectrum range.

2.5 Spectrum Planning

With the growing pressure for additional unlicensed spectrum, the Commission is also urged to plan for the allocation of additional spectrum for future licensed wide-area mobile systems. For example, very-high-speed very-low-cost mobile wireless systems may utilize about 20 MHz of spectrum per channel. Urban markets would require at least 8 – 10 channels of contiguous spectrum to accomplish build-out of a viable future wide-area mobile wireless system. These spectrum requirements should be accommodated in the planning of future spectrum allocations in the 1 to 6 GHz bands.

In order for manufacturers to expend the considerable funds needed to develop future wide-area mobile systems today, assurances that spectrum will become available for economically viable systems must be considered. For example, it would be useful to know an approximate allocation for the final system. This would allow modifications of delay spread, power requirements, etc. to be made so that a more complete understanding of deployment costs can be made. Ultimately, it is the understanding of these economic considerations that will determine the viability of a system for the public.

The Commission should also view spectrum as a limited natural resource that is needed to fuel the wireless telecommunications industry. Ideally, the Commission would look 7 - 10 years into the future and try to envision the types of services that might be useful and economically viable, one such example being wide-area mobile services. Then it should identify sufficient spectrum and move to make that spectrum available to those services by the end of the 10-year or other appropriate time frame. Services already in that spectrum would be discontinued, relocated or re-facilitated with more spectrally efficient equipment as appropriate. The process of “refarming” the spectrum of course must consider the relative priority of existing services. During that 10-year or other appropriate time frame, the Commission should grant experimental licenses for the purpose of developing the equipment needed for the new services. The Commission should also encourage incumbents to cooperate with experimental activities in a band, when it has been determined that the band is to be reallocated. Having the assurance that the raw spectrum resource will be available gives manufacturers and service providers the needed incentive to invest time and energy into these bands, while the 10-year period gives them enough time to develop the new technology. Furthermore, these frequency allocations should be coordinated globally, producing spectrum harmony and maximizing the potential market.

3 Future Unlicensed Spectrum

3.1 Unlicensed Rules

3.1.1 Scope of rules

Three alternatives are identified for the scope of rules for future unlicensed spectrum.

1. *Free-for-all:* Minimal rules usually specifying only maximum transmit power, maximum antenna gain, emission mask and sometimes channel definitions.
2. *Framework for Coexistence:* More comprehensive rules usually specifying spectrum access requirements, maximum spectrum occupancy limits, etc. to provide for equitable access to and utilization of spectrum without disadvantage to particular uses.
3. *Industry Standard:* Broad and wide ranging rules requiring adherence to an industry standard.

Alternative #1 has been the norm for the majority of current unlicensed spectrum allocations. It encourages innovation and permits deployment of a wide variety of different types of devices in the spectrum. Unfortunately, this wide diversity of design leads to coexistence problems as use of the spectrum increases. Although some have characterized the coexistence problem as "survival of the fittest", survival is not based as much on technological superiority as the type of use. Uses that are most vulnerable to uncontrollable interference, such as real-time applications requiring low latency and high quality of service, are easily forced out of the spectrum by non-real-time uses. Furthermore, even the remaining non-real-time uses cause interference to each other, resulting in poor spectrum efficiency and disruption of service. Therefore, additional allocations of unlicensed "free-for-all" spectrum are not recommended.

An early version of alternative #2 has been defined for a small spectrum allocation in the unlicensed PCS[7] band. It provides flexibility for innovation, although not as great as alternative #1, and permits deployment of different types of devices in the spectrum. However, the rules also provide order in the spectrum by specifying rules that provide a level playing field for all uses. The rules also promote high spectrum efficiency by enabling harmonious coexistence amongst different devices. The rules provide a framework for the development and evolution of industry standards that, in effect, cooperate with each other for the common good. While implementation of systems in the unlicensed PCS band has not been as great as in bands where 802.11 devices operate, this is largely due to the small size of the unlicensed PCS band. Alternative #2 is the preferred alternative for future unlicensed spectrum allocations and is discussed in more detail in section 3.1.2.

[7] Part 15, Subpart D, Unlicensed Personal Communications Service Devices

Alternative #3 has been widely practiced in Europe. The adherence to a single industry standard provides for coexistence of devices and high spectrum efficiency. However, innovation is severely restricted and a single standard may not provide for all uses. A recent example of the downside of this approach is HiperLAN/2 that has failed to attract sufficient industry support. As a result, Europe is now moving closer to alternative #2 through an initiative to permit other standards (e.g., IEEE 802.11) to operate in the spectrum, provided channel access rules (i.e., dynamic frequency selection) are observed. Since adherence to a single industry standard is encumbered with significant issues, this alternative is not recommended.

3.1.2 Reasons for New Rules

Unlicensed spectrum presents several unique problems compared to licensed spectrum. First, while the reuse of the spectrum based on frequency, time, and/or codes is planned and coordinated for high efficiency and a minimum of interference in licensed spectrum, such planning is not feasible in unlicensed spectrum. Second, licensed spectrum is managed via central control to prevent a device from accessing a channel in use by another device. No central control exists in unlicensed spectrum and interference is typically uncontrolled. Third, systems deployed in licensed spectrum are engineered to provide the quality of service needed by the intended use, including mission critical applications. Unlicensed spectrum is normally only suitable for casual use, since the quality of service cannot readily be controlled.

What is needed to address these issues in unlicensed spectrum? Explicit planning or central control is not feasible. However, decentralized spectrum management is possible for unlicensed spectrum through a set of new rules that enable harmonious coexistence of many different devices.

3.1.3 Proposed New Rules

As the Commission alluded in Public Notice DA 02-1311, as congestion rises some uses of unlicensed spectrum are at a distinct disadvantage under current rules. The major characteristics of such disadvantaged uses are typically real-time applications with a low tolerance for delay and the need for very high quality of service. New types of rules are needed to provide for equitable access to and utilization of unlicensed spectrum without disadvantage to particular uses. Such rules would provide a level playing field and permit all uses to coexist while attaining the required level of performance.

These new rules should apply to any future unlicensed spectrum allocation and be developed in advance of such allocation. The proposed rules are given below.

- Channel Definitions

Channel definitions are needed to permit efficient sharing of the spectrum by different devices. Such definitions also enable the operation of channel access rules by specifying the location and structure of the channels to be monitored.

- Power Control Requirements

Rules are needed to provide for a reduction in interference when possible. Therefore, power control requirements should be imposed. Transmit power should be limited to the minimum required for effective communication. Such power control rules will minimize unnecessary interference in the spectrum and improve overall spectrum efficiency.

- Spectrum Access Rules

Rules of access to the spectrum are required to control interference to the uses most vulnerable to interference. Without such rules, a “free for all” is the result. As previously mentioned, survivability in a “free for all” is not based as much on superior technology as the type of use. The access rules also provide a means of decentralized reuse planning to improve overall spectrum efficiency.

The fundamental mechanism to control interference and improve spectrum efficiency is monitoring the spectrum before access and determining which channels (a) provide acceptable quality for communication and (b) create a minimum of interference and disruption of service to other devices using the spectrum. Typically, monitoring of the spectrum is based on power measurement of the transmissions of other devices. These access rules also provide a form of decentralized reuse planning, since devices will access channels that minimize co-channel interference. These rules in concert with the channel definitions can also be defined to address the “hidden node” problem and further reduce unintended interference to other unlicensed devices.

- Limits on Spectrum Use

Limits on spectrum use are needed to enable fair access to unlicensed spectrum bands. This will prevent “spectrum hogs” from monopolizing the spectrum to the exclusion of others. The limits could take the form of maximum spectrum occupancy rules. Such rules should be a function of the degree of congestion; i.e., a high (or no) limit when the spectrum is essentially unoccupied by others and progressively lower limits as the spectrum becomes more congested. However, higher occupancy may be permitted if the transmissions utilize a reduced power level. This encourages higher overall spectrum efficiency by reducing the interference and reuse distances to other devices.

3.2 Spectrum Sharing / Underlay of Unlicensed Transmitters

There are many proponents of the underlay of unlicensed transmitters in order to share spectrum that is currently authorized for other licensed services. In this arena, transmitters would be “licensed-by-compliance as long as they “do not interfere with existing services.” The bands that were discussed often during the FCC Public Panels held in August 2002 include:

- DoD / Government Spectrum
- Broadcast Spectrum (Spectrum utilized for commercial, entertainment television and radio transmissions)
- Public Safety (The VHF, UHF, 800 MHz, and now GHz bands currently allocated to public safety interests)
- Land Mobile Spectrum
- Amateur Radio Spectrum

In fact, some proponents of underlay usage have indicated that ALL spectrum should be available on a non-interfering basis. Such discussions inevitably rely on arguments that smart and/or cognitive radios can determine the level of usage of a given spectrum choice and operate during those portions of time when the spectrum is not in use. While the argument can be made that it would seem that much of the radio spectrum is under-utilized or not used at all, proving so is a very difficult task. It is not as simple as just hooking up an antenna and listening on a given frequency to determine the usage as some have suggested. What may seem like unused spectrum from one monitoring point, may in fact be occupied by a point to point, satellite, or critical use linked system with a distant transmitter relaying information to a very close, but undetectable receiver. If transmission were to occur on the channel, interference to the licensed service would occur without the underlying system even knowing about it. Certainly Public Safety applications cannot survive with the 99th percentile performance expected when interferers crop up unknowingly. This will become increasingly important as the evolution to digital communications of voice, data, and multimedia continues in these services. As these allocations become populated at higher duty cycles with these new, higher-bit-rate services, the potential of interference also rises accordingly. Protected spectrum equals protected services for these important public safety and homeland security communications.

Some have claimed that some spectrum available for public safety use is underutilized. The public safety community has well documented that need in the Public Safety Wireless Advisory Committee (PSWAC) Final Report dated September 11, 1996. Recent terrorist events further underscore the need for sufficient public safety spectrum that is not compromised by the presence of other users such as unlicensed underlay operations. Public safety communications must be kept interference-free if lifesaving communications are to be maintained. In Appendix C, duplex, voted communications systems and the possibility of interference is discussed. It is difficult to ensure that a channel will be free and clear when it is needed if nomadic traffic is allowed to coexist.

Further, public safety will become increasingly congested with the advent of new mobile data services. Product development projects are currently underway by several manufacturers, including Motorola, for high-speed, robust data systems in the new 700 MHz spectrum being re-farmed from broadcast television to public safety. These systems utilize channels up to 150 kHz to convey timely data to police officers, firemen, and others, allowing them to have access to the most up-to-date information. This data can include speech, text, real time video, and other services. The critical need however, is to actually clear this spectrum of incumbent television operation so it can actually be deployed everywhere in the country for public safety operations. It has been 5 years since this 700 MHz spectrum was allocated to public safety and yet it is still unavailable in half of the top 80 cities in the U.S.

Likewise, wireless services that are relied on by the general public must be as reliable as possible. While wireless communication was once a luxury, it is now an important means of communications relied on by over 50 percent of the population, including for use during emergencies to contact 911 services.

The ability to monitor and accurately determine if transmitting can cause interference to the primary users of the spectrum is impacted by many factors. One factor is shadowing of the smart and/or cognitive radio antenna. If the monitoring antenna is in a shadow or coverage hole with respect to the licensed transmitter, it will be unable to detect its presence. As a result, the smart and/or cognitive radio may transmit and cause unintended interference with unknown consequences. A second factor is time. Even if a smart and/or cognitive radio determines that spectrum is not used at the present time, there is no ability to look ahead in time. Therefore, immediately after the smart and/or cognitive radio starts transmitting, the licensed transmitter may begin a transmission and interference will result. A third issue is the exclusion zones. The power transmitted by a smart and/or cognitive radio will define an exclusion zone around it wherein interference with any licensed receiver within the zone will result. The specific area and shape of the zone are a function of the propagation path loss between the licensed receivers and the smart and/or cognitive radio. Given a low loss propagation path, the smart and/or cognitive radio could cause interference to a relatively distant licensed receiver. These factors are difficult to control or predict. Motorola has recently begun an investigation of technologies supporting fast radio resource management making use of simultaneous spectrum occupancy measurements at different geographic locations in a system.

While allowing operation of cognitive radio, or other forms of spectrum sharing seems inviting, in many cases, the risks appear to far outweigh any potential benefit at this time. The problems of shadowing of the monitoring antenna, inability to look ahead in time, and the exclusion zone of interference to the primary service must be resolved or at least ameliorated. Much more research is required before any such consideration should be made to revamp the current rules with respect to allowing such sharing, particularly in heavily encumbered bands or in bands used for critical services.

4 Experimental Licensing and Spectrum

4.1 Set-aside Spectrum for Pro-active System Development

Historically, the Commission has been reactive to technology and the need for spectrum allocations. Examples of this are numerous: The re-allocation of TV channels 70 – 83 for cellular and public safety usage being only one case. While this approach was adequate in the past, rapid advances in the technology and the public move towards the use of spectrum – both licensed and unlicensed – has brought about the need for a different approach in the re-allocations of spectrum. While it can basically be stated that all spectrum from near-DC to at least 28 GHz has been allocated to one service or another, there are considerable demands being placed on the prime spectrum (defined herein as allocations in the 150 – 6000 MHz range) for re-allocation and / or shared usage. While the current march is for increasing amounts of unlicensed spectrum, the Commission is urged to identify spectrum for future wide-area mobile technologies. Such systems have the potential of carrying in excess of 100 Mb/sec to mobile and fixed customers. Development of these systems is expensive and deployment of any system is, at best 3 years away, and more likely 5 – 7 years from reasonable deployment. To develop such systems, research entities, whether they be in the commercial sector or in the government / university sector, need to have access to spectrum that can be utilized for rather lengthy periods of time. In addition, the development and test of software-defined and cognitive radios will also require clear spectrum in which to gain knowledge without impeding other licensed services. Motorola urges the Commission to set aside a relatively small part of the spectrum for such developmental work. Specifically, Motorola suggests that the Commission identify at least 50 MHz of spectrum between 2 and 4 GHz for development of advanced mobile communications systems. This should be part of the long-term spectrum plan to support future wide-area mobile systems with the intent of making additional spectrum available as the technology becomes viable and demand is demonstrated.

4.2 Access to Government Spectrum for Export Development

In some instances, experimental licenses are necessary to develop and test equipment in the U.S. that is destined for export sales. Often times, this requires short-term use of spectrum allocated for Government services and therefore under the control of the NTIA. The NTIA, under the auspices of the Department of Commerce, should welcome such use of the spectrum on a coordinated basis, especially when the outcome is sales of product into foreign countries, which helps the balance of trade. Under the current procedures, an application for experimental license is filed with the Commission. If Government spectrum has been requested, the application is forwarded to the NTIA and the IRAC for consideration. Improvements in the cycle time of IRAC processing would assist U.S. companies be more competitive in the global market. Although it has been stated that the IRAC turnaround is usually on the order of 15 days, Motorola has at times experienced delays of 12 months or more. In most instances, a 12-month delay would mean the difference between successfully deploying product into a foreign marketplace or being denied critical sales. Delays longer than a few months usually negate the competitive nature of such business in favor of competitors.

Motorola suggests the following formula to improve cycle time on processing experimental licenses for export product development and testing when the spectrum, encompasses bands under NTIA's jurisdiction:

1. The Commission should have the ability to analyze the impact of interference to Government spectrum from the proposed experimental license and assist the NTIA in reaching a mutually agreeable conclusion to grant or deny the license.
2. Requests for experimental licenses should be handled in a timely manner; i.e., less than 90 days.
3. Procedures should be established for applicants to work directly with NTIA to quickly address any concerns and to develop mutually acceptable conditions for any experimental use, including, but not limited to:
    a. Limited hours of operation,
    b. Provision of a "hotline" by which immediate cessation of transmission can be implemented if requested by the NTIA, DoD or any impacted government agency.
4. The FCC database should be merged, wherever possible, with the NTIA database of spectrum usage so that spectrum usage can be more easily determined.

In #4, above, an example of the glaring holes present in the current database is the allocation of over 3000 NOAA weather radio transmitters authorized in the United States. One need only do a search of the FCC database for 162.400 MHz through 162.550 MHz for this example. No licenses will be indicated for the NOAA broadcasts; a cognitive radio only utilizing a database to determine holes in which to operate could inadvertently begin transmission on one of these critical channels.

4.3 The Current FCC Experimental Licensing Plan is Efficient when non-Government Spectrum is Requested.

Since the revision of the Part 5 rules in 1998, the process of obtaining and utilizing experimental licenses has been dramatically improved. Licenses are generally issued in a timely fashion and the Commission is sufficiently reactive to requests for STAs and situations that require expedited action. The only area of licensing that should be considered for modification is that of renewal of experimental licenses. Motorola would propose that 2 and 5 year <u>experimental license renewal applications be allowed for filing 90 days</u>, rather than 60 days, prior to expiration. This would help ensure experiments in process could continue unimpeded, given the additional time for possible responses to Commission questions and inquires. Allowing renewals to only be filed within 60 days of expiration results in business uncertainty and could result in temporary suspension of the experiment if the renewal can not be granted in time. Even one day of delay can cost thousands of dollars in engineering time.

References

[1] David P. Reed, “How wireless networks scale: the illusion of spectrum scarcity”, presentation to the FCC Technological Advisory Council, April 26, 2002.

[2] David P. Reed, “Comments for FCC Spectrum Policy Task Force on Spectrum Policy”, comments in response to ET Docket 02-135, July 8, 2002.

[3] Timothy J. Shepard, “Decentralized Channel Management in Scalable Multihop Spread-Spectrum Packet Radio Networks”, Ph. D. dissertation, Laboratory for Computer Science, Massachusetts Institute of Technology, July 1995.

[4] Piyush Gupta and P.R. Kumar, “The Capacity of Wireless Networks,” *IEEE Transactions in Information Theory*, Vol. 46, No. 2, March 2000.

[5] Paul Kolodzy et al., “NeXt Generation Communications: Kickoff Meeting”, DARPA, October 17, 2001.

[6] V. H. McDonald, “The Cellular Concept”, *The Bell System Technical Journal*, Vol. 58, No. 1, January 1979.

[7] William Fifer and Frederick Bruno, “The Low Cost Packet Radio”, *Proceedings of the IEEE*, January 1988.

[8] David Larsen and James Larsen, “Multi-Hop Packet Radio Networks”, World Patent number WO 96/19887, June 27, 1996.

[9] Rodger Ziemer and Roger Peterson, *Introduction to Digital Communication*, Second Edition, Prentice-Hall, Upper Saddle River, NJ, 2001.

[10] Roger Peterson, Rodger Ziemer, and David Borth, *Introduction to Spread spectrum Communications*, Prentice-Hall, Upper Saddle River, NJ, 1995.

[11] S. Benedetto et al., "Serial Concatenation of Interleaved Codes: Performance Analysis, Design and Iterative Decoding", *IEEE Trans. Info Theory*, Vol. 44, No. 3, May 1998.

[12] Mark Klerer, “Broadband Mobile Wireless Access SG, PAR and Five Criteria Working Document”, C802.16sgm-02/11, June 11, 2002.

[13] K. C. Allen et al., “Building Penetration Loss Measurements at 900 MHz, 11.4 GHz, and 28.8 GHz, U.S. Department of Commerce, NTIA Report 94-306, May 1994.

Appendix A - Definitions

Beyond 3G Systems: Systems that use both 3G and WLAN technologies collaboratively to provide customers both wide-area voice and medium-rate data and hot-spot high-rate data services. A radio resource manager assigns a user to 3G or WLAN taking into account the user communication needs and the user location.

Cognitive Radio: A radio system that is able to learn about its physical environment and about the needs of its user and to use this information to better service a user. Cognitive Radios are enabled, in part, by Software Defined Radio technology. Cognitive Radios will have the ability to adapt transmission parameters to, for example, the multipath and interference environment Cognitive Radios may be able to dynamically share spectrum with the assistance of a fast radio resource manager.

Electronic News Gathering (ENG): The use of 2 GHz, and higher, frequencies to broadcast live video from remote locations back to a television studio. This can also be accomplished through the use of satellite links.

Overlay System: Similar to Underlay System, an Overlay System utilizes un-used spectrum in a given geographical location. Currently, Overlay Systems are licensed alternative services. An example is the use of UHF television spectrum for directional, low power STL links.

Software Defined Radio (SDR): A class of reprogrammable or reconfigurable radios designed such that the same piece of hardware can perform different functions at different times. The ultimate SDR is a radio that is fully programmable and supports a broad range of carrier frequencies, air-interfaces, and applications software.

Smart Radio: For the purposes of this white paper, a transceiver that monitors a channel prior to transmission and determines whether or not the channel can be utilized without causing interference.

Special Temporary Authorization (STA): A short term usage alternative to Experimental, Part 5 licensing which can be utilized to do short term testing of systems or test new modulation methods or communications systems on existing services.

Studio to Transmitter Links (STL): In the broadcast television and radio services, these are links that convey the program information from a studio location to a remote transmitter site.

Underlay System: Any licensed or unlicensed transmission that is intended to occupy spectrum assigned to another service on a non-interfering or minimally interfering basis.

Appendix B - Smart Radio vs. Cognitive Radio

Cognitive Radio is a term defined by J. Mitola[8, 9] of MITRE Corporation to describe a radio and associated radio system that is highly adaptive to user needs and to the current physical environment and that has the capability to learn and adapt automatically. The purpose of the adaptation is to make the most efficient use of spectrum resources while servicing a wide range of user applications. The ability of the radio system to learn and adapt automatically is considered essential due to the complexity of the total adaptation problem. The term *cognitive radio* has recently been applied to radio systems that do not learn but that do have a high degree of flexibility to adapt to the radio communications physical environment. Motorola agrees with the assessment of J. Mitola that learning will be required to achieve the long-term goal of obtaining the highest public value from the radio spectrum. However, Motorola also believes that this long-term goal can be achieved via smaller steps that may not, at first, require a learning ability in the radio system or user equipment.

Cognitive radios are enabled by software defined radio technology. The cognitive radio must be able to adapt the physical layer and possibly higher layers of a communications link to the physical environment and / or to the traffic conditions. This requires that the radio be reprogrammable to a large number of transmission standards. The cognitive radio may even be able to convey information about the multipath characteristics of the current channel to a system controller; this information could be considered in the waveform selection. In addition, cognitive radios may have the ability to measure spectrum occupancy over a prespecified range of frequencies and relay that information to a controller for use in the determination of carrier frequency and waveform. Cognitive radio is the subject of ongoing research both by equipment manufacturers and the Government. The gains in spectrum efficiency that might be achieved through the use of this revolutionary technology are not yet known.

In contrast, a *Smart Radio* is a radio that has the ability to listen on a given frequency, or a range of frequencies, prior to transmission and therefore has the ability to avoid transmitting on a channel that it knows is being used. The only knowledge the smart radio has is that, at the time of transmission, the frequencies to be used are vacant. Smart radios exist today. For example nearly all 2-way land mobile products have a primitive smart radio feature that listens to the un-squelched channel before transmitting. Smarter trunked radio systems rely on a listen-before-transmit feature as well as a control channel to organize the traffic.

It is important to note that smart radios can only tell if a transmitter is in the area and broadcasting on a channel under consideration for use by the smart radio itself. <u>A smart</u>

---

[8] Joseph Mitola III, "Cognitive Radio: Making Software Radios More Personal", *IEEE Personal Communications*, Vol 6, No 4, August 1999.

[9] Joseph Mitola III, "Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio", Dissertation for the degree of Doctor of Technology, Royal Institute of Technology, Kista, Sweden, May 8, 2000.

radio has no means to tell where a receiver, or multiple receivers in a voted or multi-point system, are located. Therefore, interference protection by an underlay system cannot be guaranteed, or even anticipated, for many current spectrum allocations. A cognitive radio provides the possibility of interference avoidance, but only in those cases where an accurate database exists to instruct the cognitive radio where receive points are located.

Appendix C - The Potential Effects of Underlay Systems on Licensed Services: Two Examples

Consider the Broadcast STL (Studio to Transmitter Link) band at 944 – 951 MHz. In all major cities, this spectrum is extensively utilized. Volunteer coordinators, generally under the auspices of the Society of Broadcast Engineers (SBE) take great pains to assign channels within the band that are dependant upon transmitter and receiver location, as well as polarity of the radiated signal. While one can tune through the STL band and probably find nothing, a transmitter that may suddenly come up on channel could interrupt the linking of program material to the transmit site. The new, underlay transmitter has no idea where the receiver is located. While the receiver may be listening to a distant, narrow beam signal which contains the program material for the broadcast station, it could easily be captured by the "underlay" transmitter which might be located very close to the receive site. In this example, the interference could be fleeting, but it would still be objectionable and, unlike most interference problems today, which are caused by spurious radiation products, this new form of interference would be nearly impossible to track down. Ultimately, rather than a single interferer, the receiver could be inundated with hundreds or thousands of interferers – especially considering a typical STL termination point such as the Sears Tower in Chicago. While a cognitive radio might be able to avoid this problem due to the fact that both receive and transmit locations are entered into the FCC data base in the case of ST links, this luxury disappears when one considers something as simple as Public Safety and Land Mobile communications.

In the case of land mobile / public safety, one or more transmit site might be licensed, but receive sites, operating on different frequencies, are not licensed. These sites can also be interfered with as in the case of the ST Link. While mobile traffic might be unaffected due to the use of multiple, voted receive sites, handheld / portable transceivers could be severely limited since an in-building 450 or 800 MHz unit might only be able to be heard by one voted site. While the argument can be made that underlie radios would not open the squelch of a CTCSS or DCS receive site, the interference to the receiver is still, nonetheless, present and could cause the loss of primary service information on a radio channel. This interference becomes increasingly deleterious as spectrally efficient, digital modulation and signaling means are introduced in the market.